INFLUENCE OF STRUCTURAL FLEXIBILITY ON THE DYNAMIC PRECISION OF A VEHICLE-MOUNTED EQUIPMENT SYSTEM

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U.S.Army RDECOM TARDEC

Report Documentation Page

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Outline

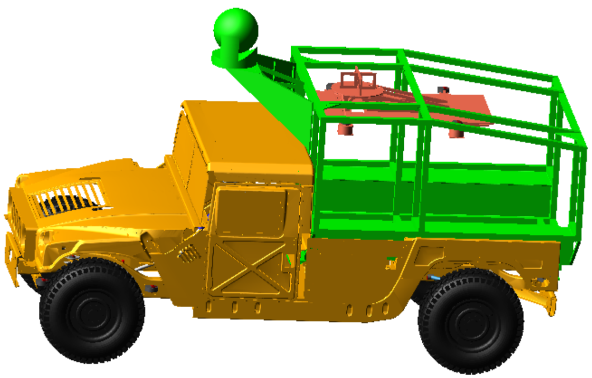
Problem Statement

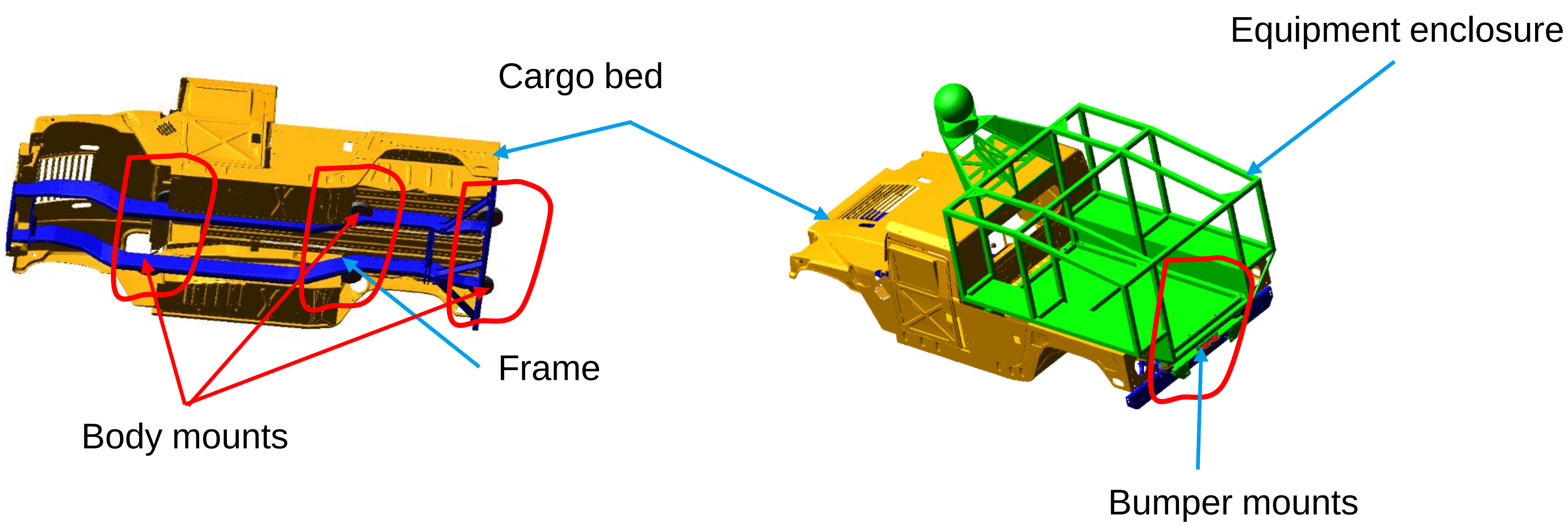
Current project is to develop a precision equipment system

- Equipment system needs to be reliable for use from vehicle platform
- Equipment system is placed in enclosure attached to cargo bed
- For the equipment system to work properly, vibration should be minimized
- Vibration coming from the road through suspension is suppressed by isolators
- Excessive vibration can cause the system to miss performance, and in severe cases can cause mechanical failure
- Need to know vehicle motion accurately to design isolators
- Rigid and flexible vehicle models are developed and simulation results compared

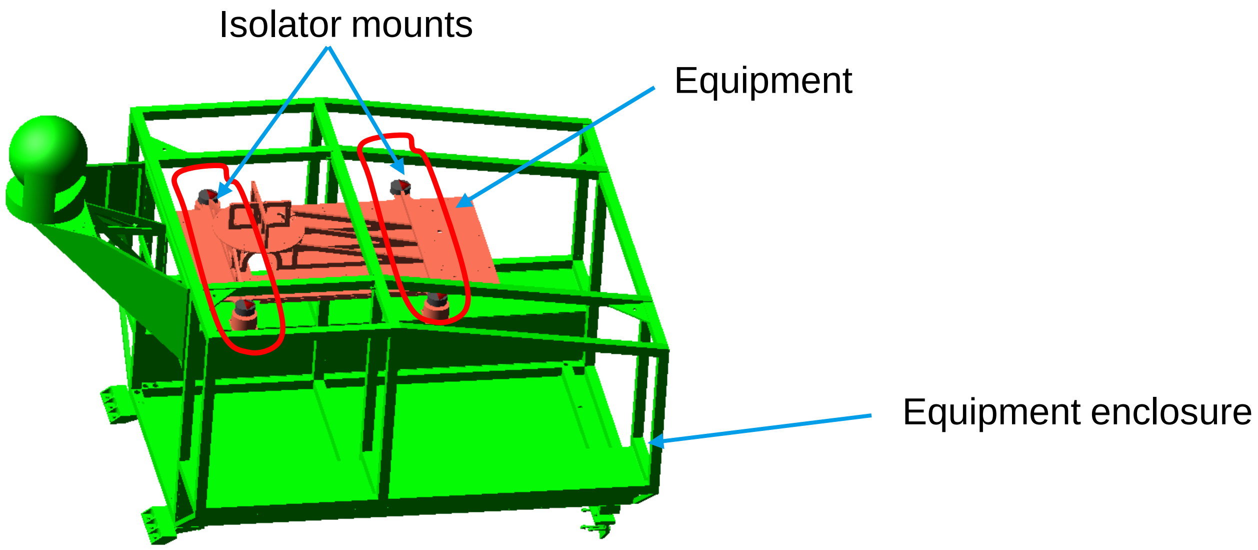
Rigid Vehicle Model

- Adams/Car Model

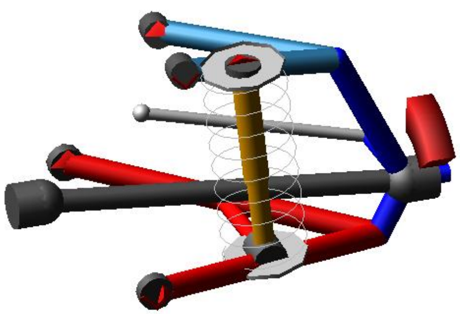




Rigid Vehicle Model



- Suspension System



Double wishbone suspension

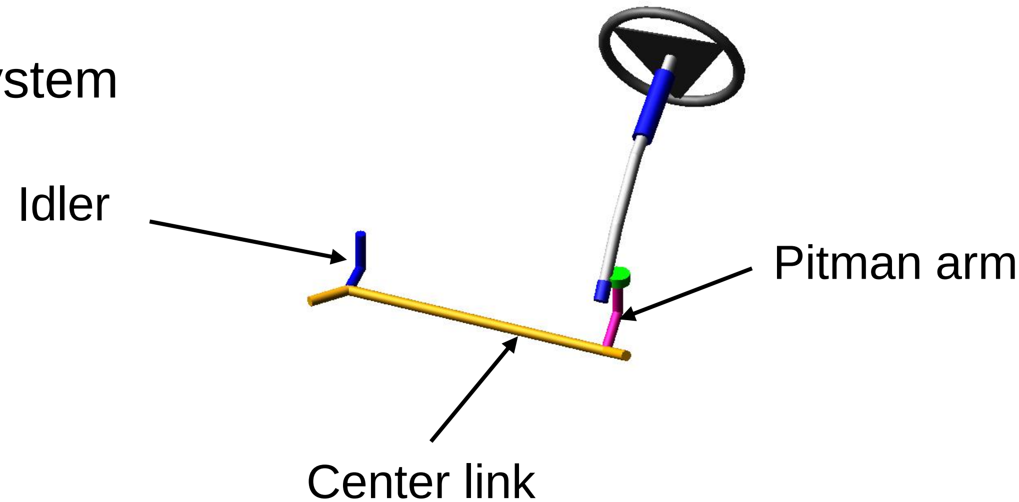
  - Springs and dampers
  - Bumpstops
  - Tierod
  - Drive shaft

Rigid Vehicle Model

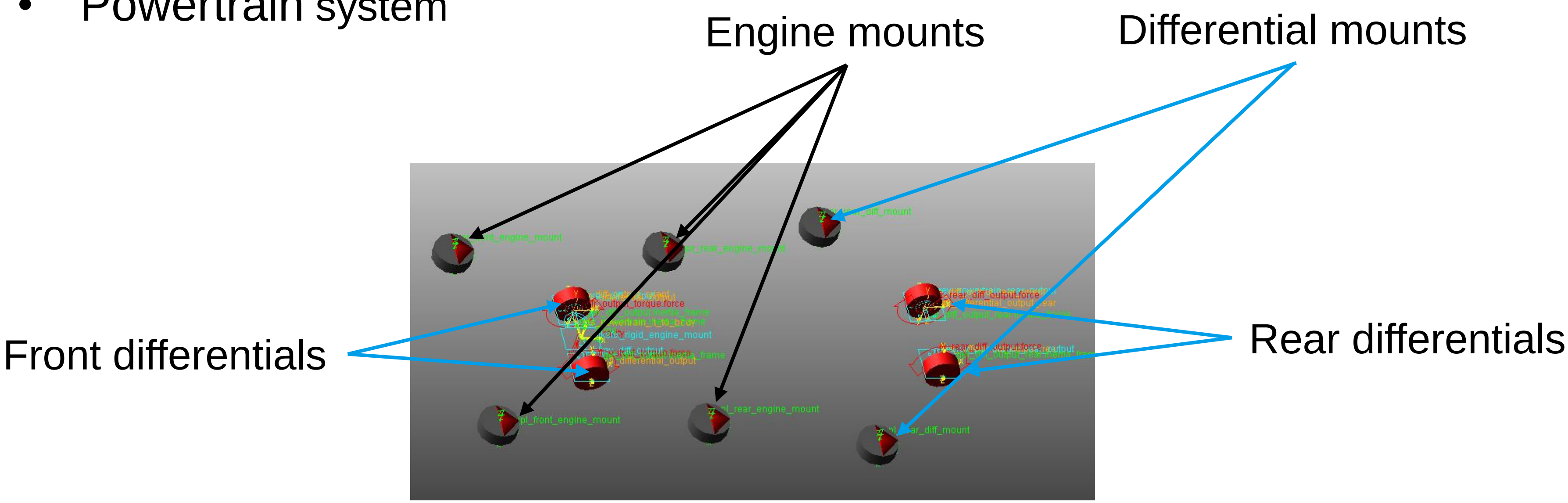
- Pacejka 2002 tires

  - Unloaded radius: 516 mm
  - Tire width: 317 mm
  - Vertical stiffness: 525 N/mm
  - Vertical damping: 3.15 N-s/mm

- Steering System

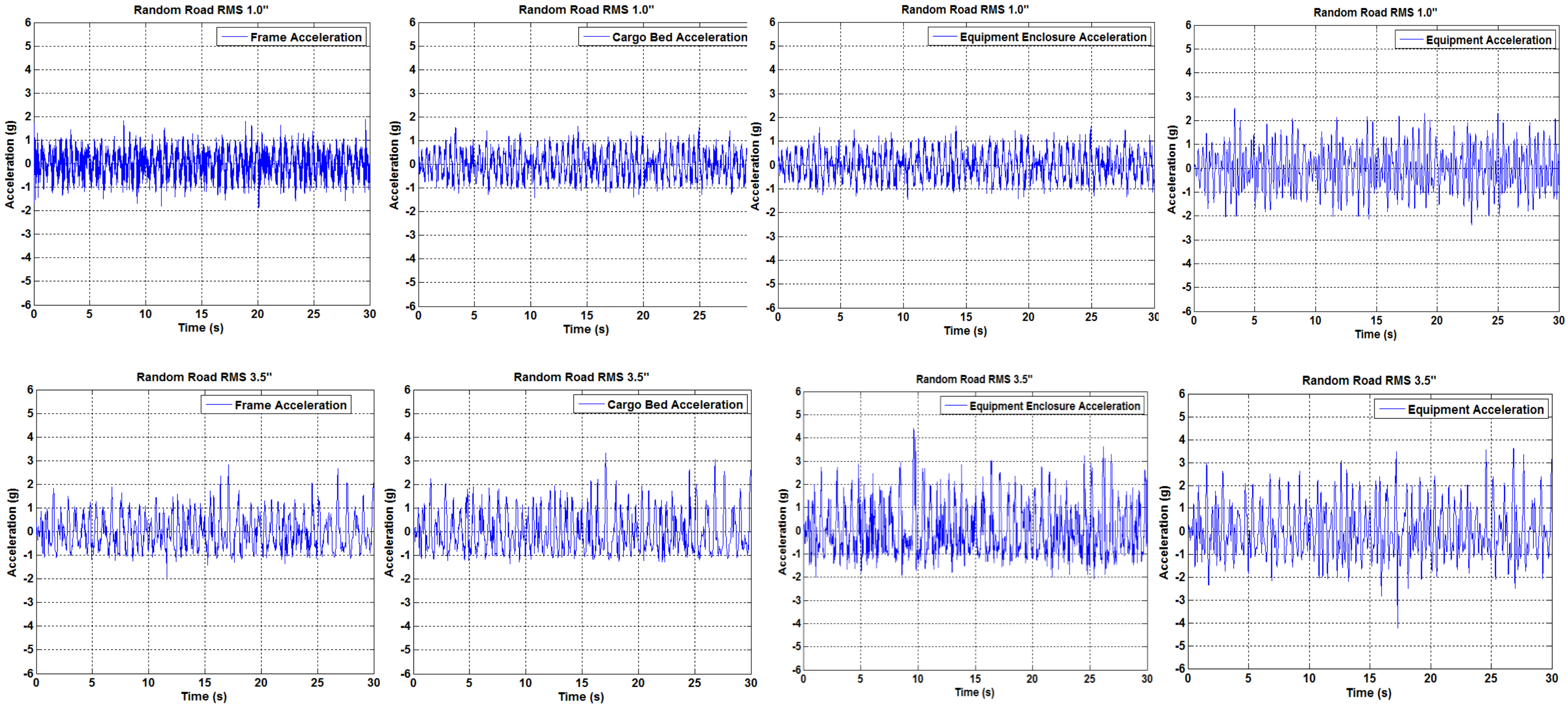


- Powertrain system



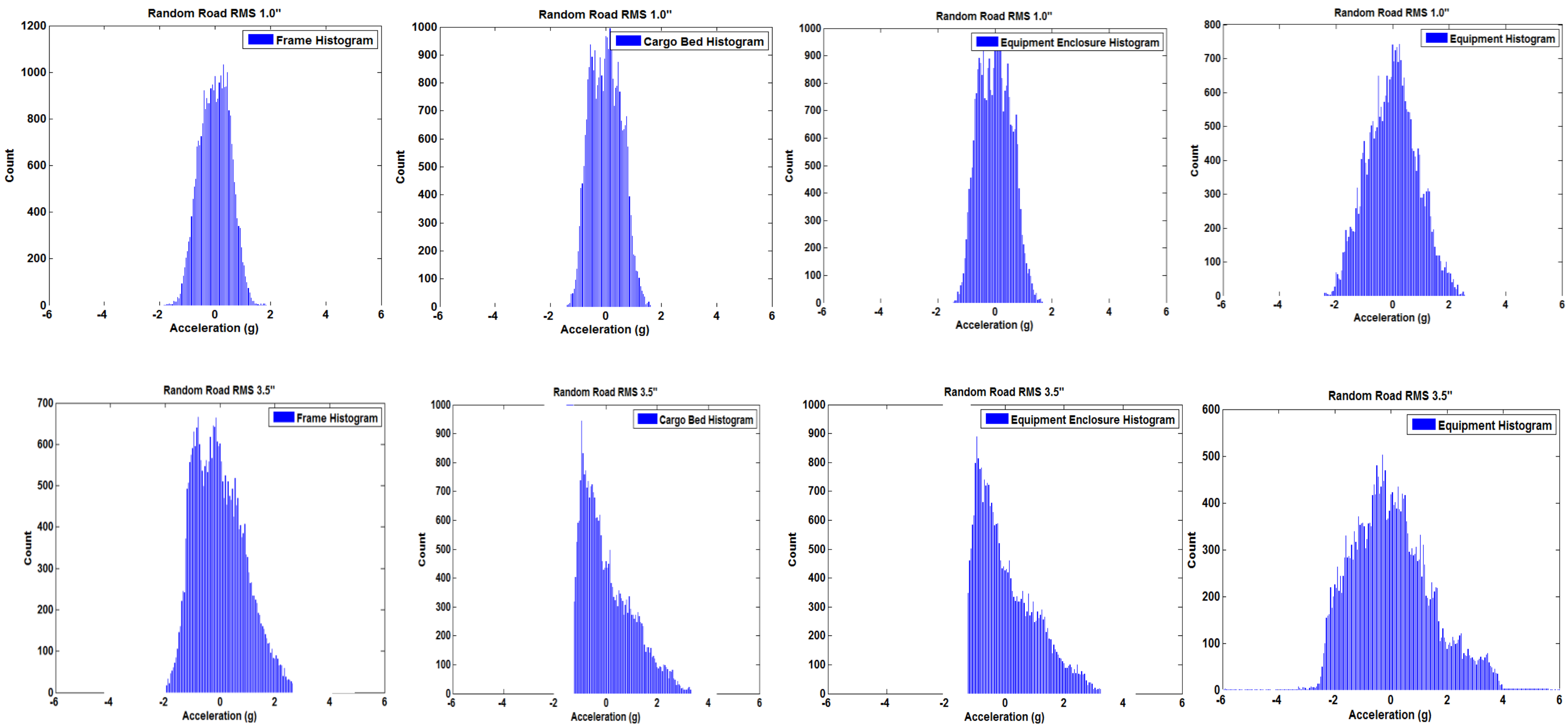
- Idle engine speed
- Max engine speed
- Max throttle
- Final drive ratio

- **Time Histories, Accelerations**
  - Low random RMS road, vehicle speed is 31 mph
  - High random RMS road, vehicle speed is 20 mph



Rigid Model Simulation Results

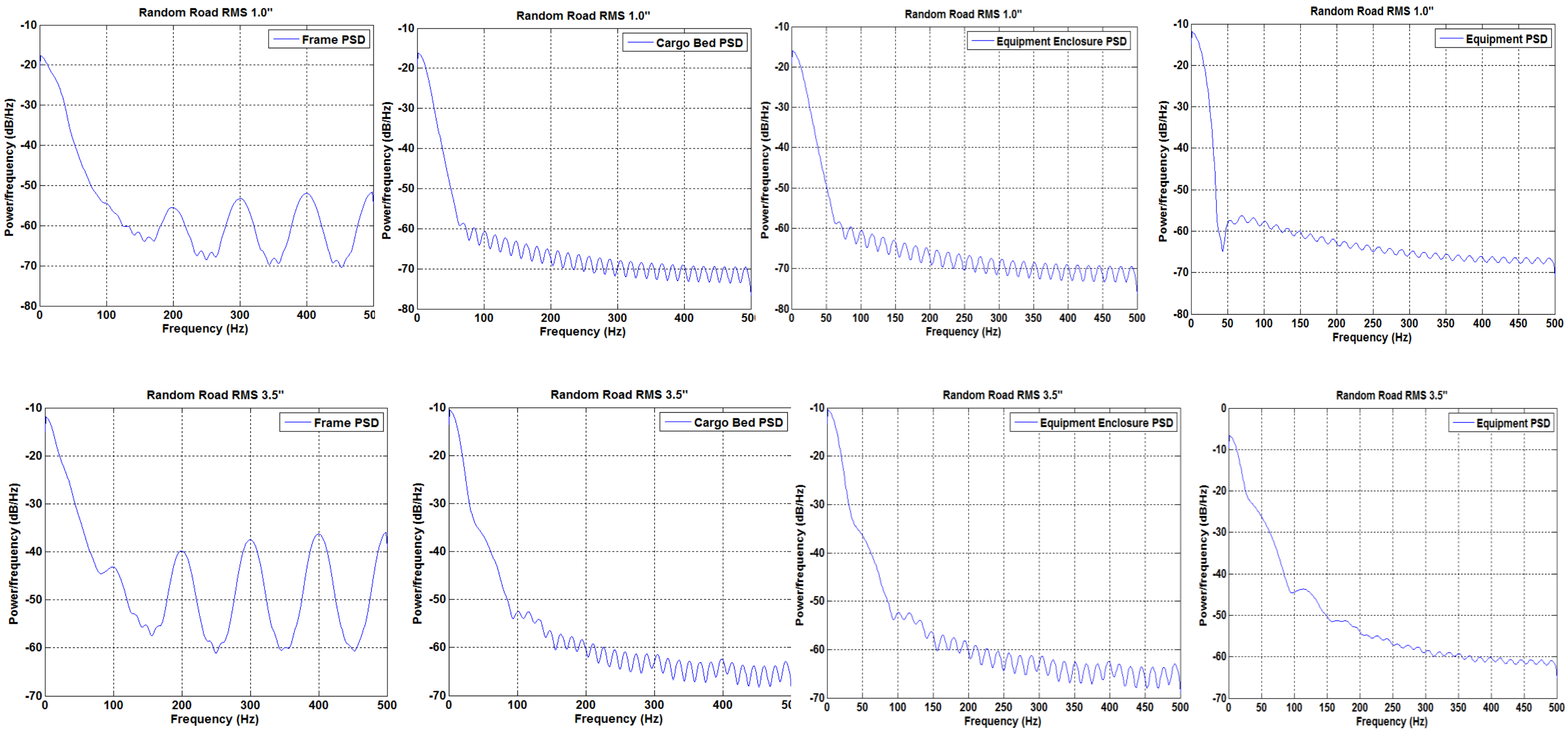
- **Acceleration Histograms**



- Random road RMS 3.5" excites higher accelerations

Rigid Model Simulation Results

Power Spectral Densities



- No low frequencies in response

Component Mode Synthesis

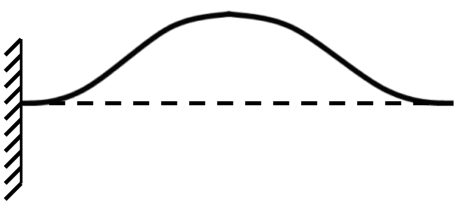
- Component mode synthesis (CMS) is a technique that allows to analyze structure by dividing it into different substructures. The substructures are analyzed separately, then assembled together
    - This technique used for large and complex structures
    - When FE components are built in different locations
- High modes in the modal analysis are truncated there is no loss in resolution, the CMS technique will capture them with the static deformation shapes
- CMS technique reduces significantly the model complexity, computational time

Craig-Bampton Method

Craig-Bampton Method *

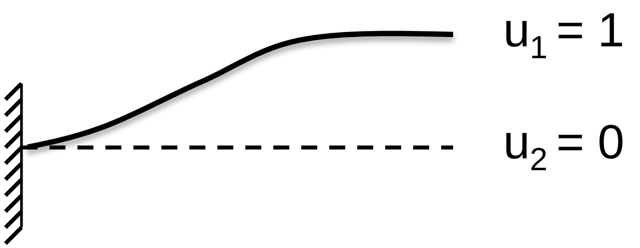
Fixed-Interface normal modes

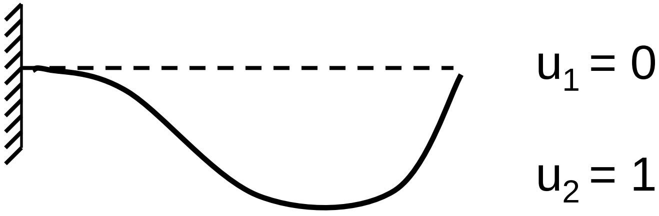
Constraint modes



$(k-\omega^2 m)\phi = 0$

Fundamental normal mode of fixed interface



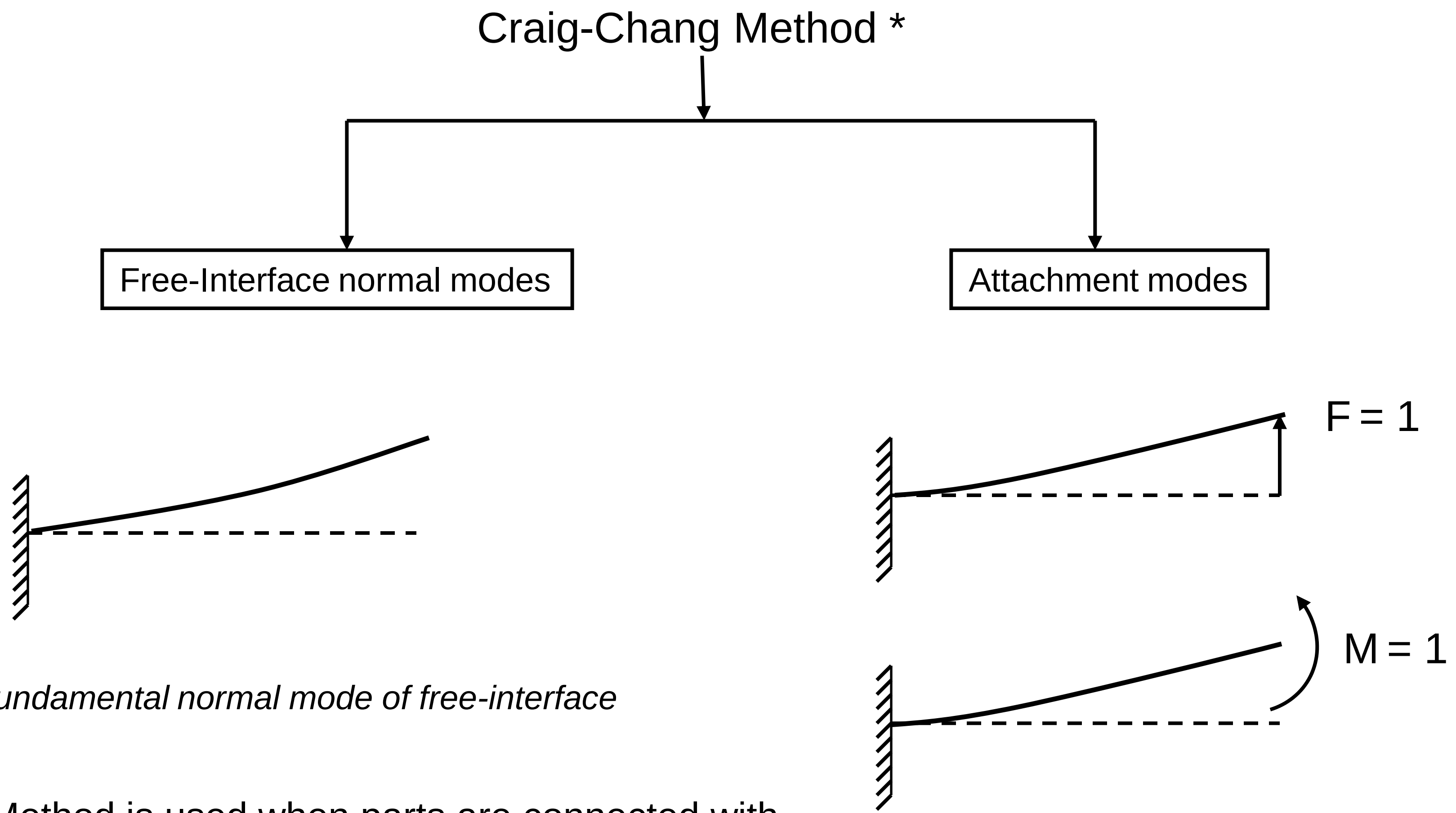


Constraint modes of cantilever beam

Method is used when parts are connected with joints

* R. R. Craig and M. C. C. Bampton, “Coupling of Substructures for Dynamic Analysis,” AIAA Journal, v. 6, pp. 1313-1319, 1968.

Craig-Chang Method



Fundamental normal mode of free-interface

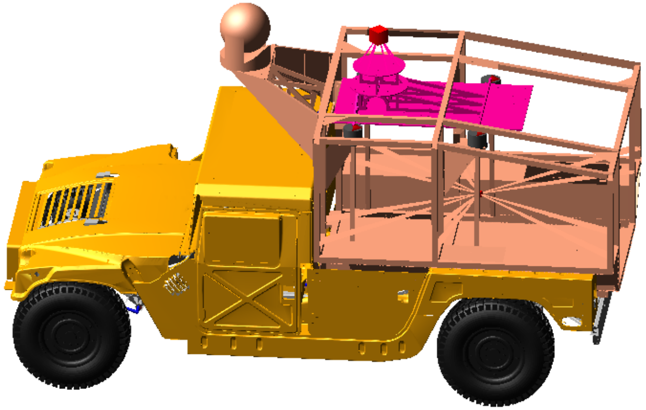
Attachment modes of cantilever beam

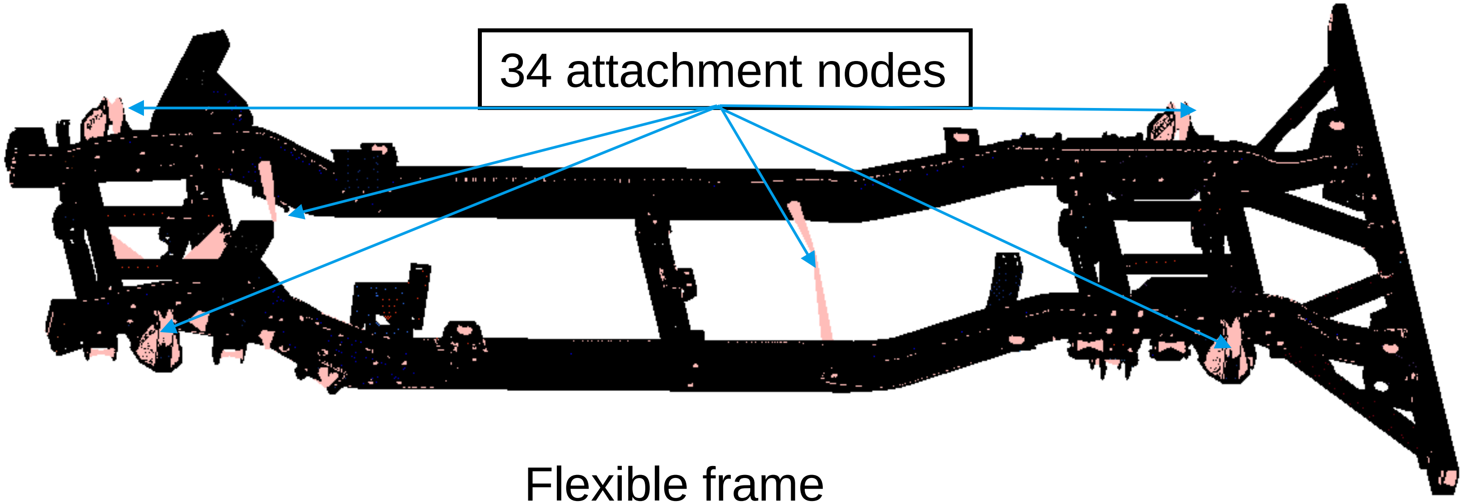
Method is used when parts are connected with
- joints that are partially constrained
- Bushings that do not have high stiffness

* R. R. Craig and M. C. C. Bampton, "Coupling of Substructures for Dynamic Analysis," AIAA Journal, v. 6, pp. 1313-1319, 1968.

Flexible Vehicle Model

Adams/car Flexible Model



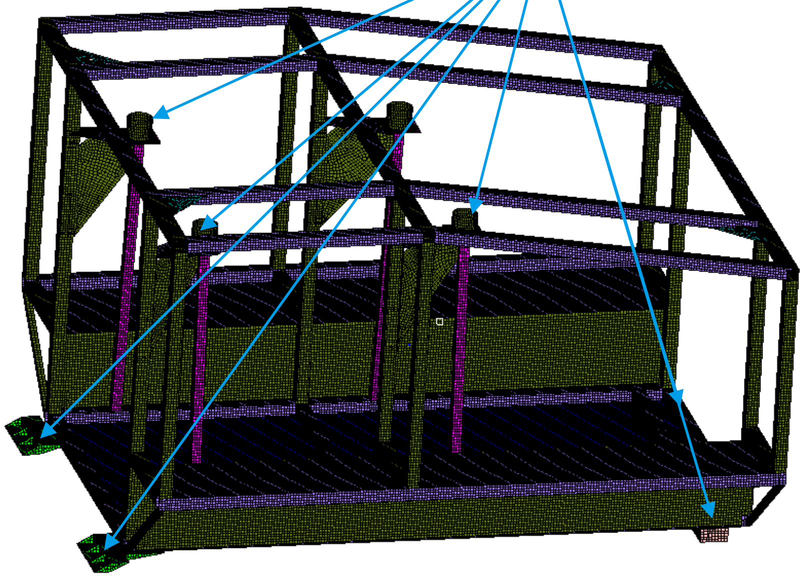


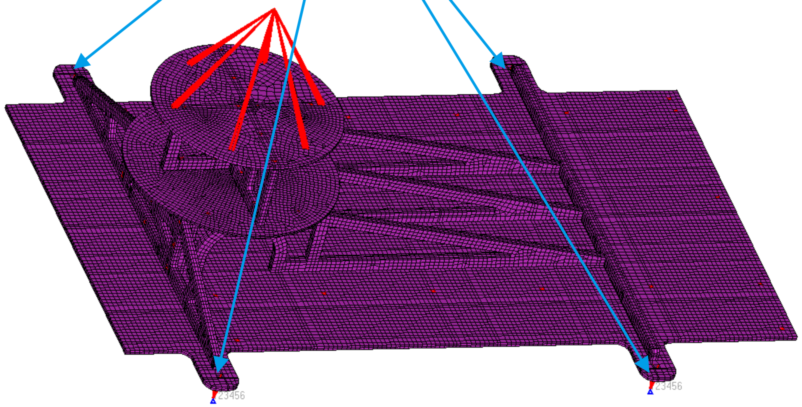
Flexible frame

Flexible Vehicle Model

16 attachment nodes

4 attachment nodes

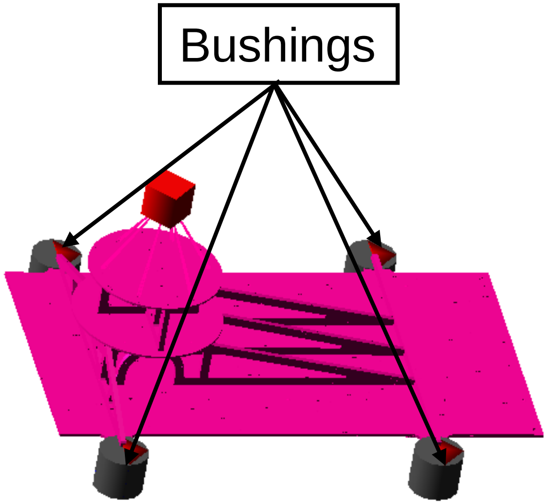




Equipment

Equipment Enclosure

CMS of Equipment



- Equipment was meshed and run for model analysis using different CMS techniques, the analysis was done using Radioss software
- Cutoff frequency is 200 Hz
- There are 4 attachment nodes

Equipment CMS Results

Craig-Bampton Method

Mode Shape	Natural Frequency (Hz)
1	39.6
2	89.2
3	135.7
4	170.4
5	204.0
6	232.9
7	334.9
8	504.4
9	676.2
10	717.9
.	.
Highest	9,550

- 24 static modes
- 8 normal modes

CMS Modes

- 32 orthonormalized modes

Craig-Chang Method

Mode Shape	Natural Frequency (Hz)
1	39.6
2	87.1
3	134.4
4	158.9
5	172.7
6	187.5
7	262.5
8	361.0
9	419.9
10	582.4
.	.
Highest	9,655

- 24 static modes
- 12 normal modes

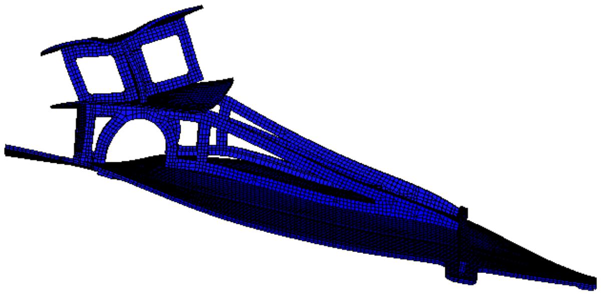
CMS Modes

- 32 orthonormalized modes

Equipment Mode Shapes and Natural Frequencies

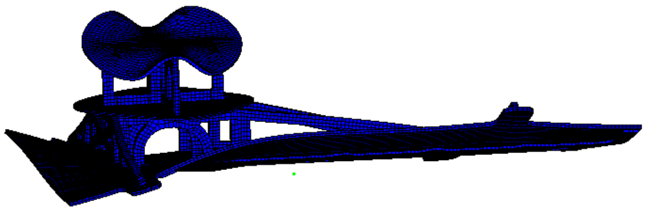
Craig-Bampton

Mode Shape 1
$\omega_1 = 39.6$ Hz



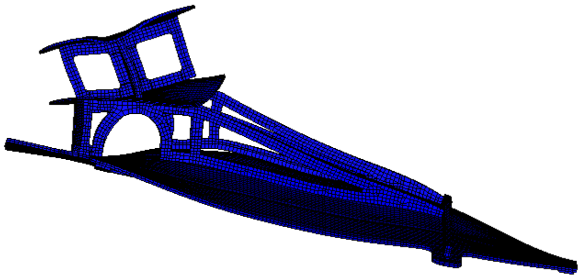
Craig-Bampton

Mode Shape 2
$\omega_2 = 89.2$ Hz



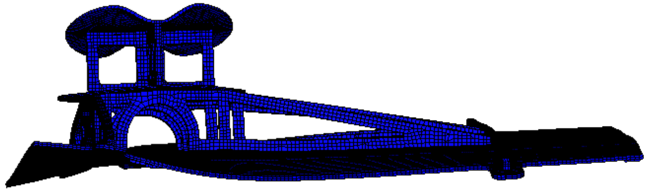
Craig-Chang

Mode Shape 1
$\omega_1 = 39.6$ Hz



Craig-Chang

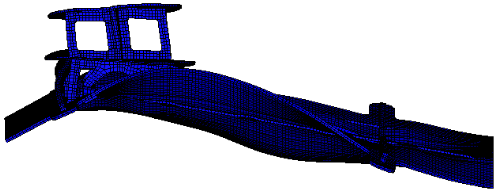
Mode Shape 2
$\omega_2 = 89.7$ Hz



Equipment Mode Shapes and Natural Frequencies

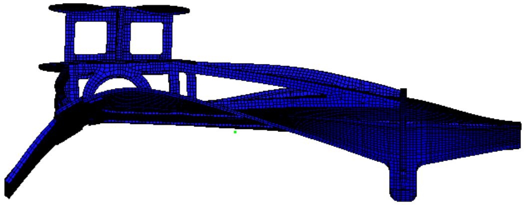
Craig-Bampton

Mode Shape 3
ω_3 = 135.7 Hz



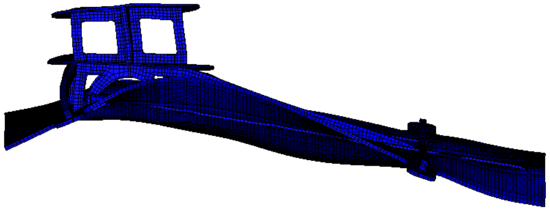
Craig-Bampton

Mode Shape 4
ω_4 = 170.4 Hz



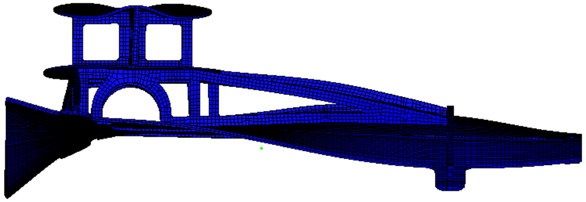
Craig-Chang

Mode Shape 3
ω_3 = 134.4 Hz



Craig-Chang

Mode Shape 4
ω_4 = 158.9 Hz



Frame CMS Results

Craig-Bampton Method

Mode Shape	Natural Frequency (Hz)
1	19.8
2	22.5
3	28.1
4	32.5
5	46.7
6	61.1
7	63.5
8	66.7
9	70.4
10	71.8
.	.
Highest	14,908

- 204 static modes
- 53 normal modes

CMS Modes

- 257 orthonormalized modes

Craig-Chang Method

Mode Shape	Natural Frequency (Hz)
1	19.8
2	22.5
3	28.0
4	32.5
5	46.5
6	60.1
7	63.5
8	66.2
9	69.5
10	71.8
.	.
Highest	15,507

- 204 static modes
- 72 normal modes

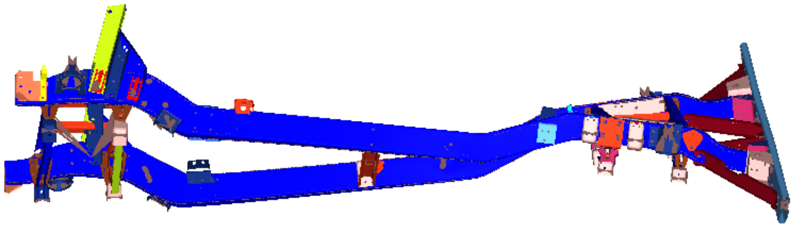
CMS Modes

- 276 orthonormalized modes

Frame Mode Shapes and Natural Frequencies

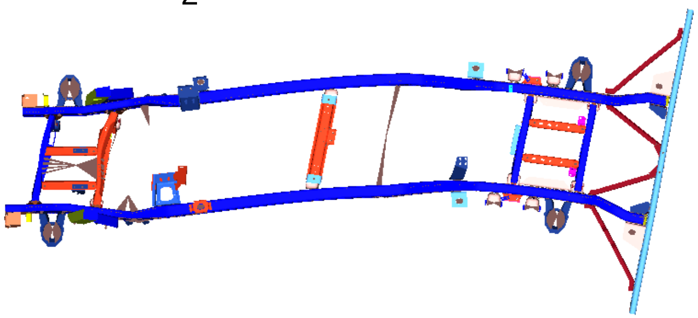
Craig-Bampton

Mode Shape 1
ω_1 = 19.8 Hz



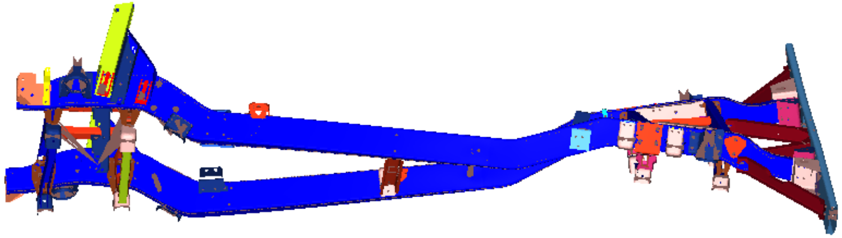
Craig-Bampton

Mode Shape 2
ω_2 = 22.5 Hz



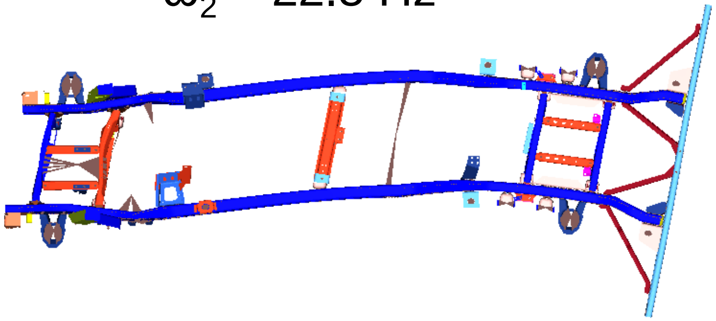
Craig-Chang

Mode Shape 1
ω_1 = 18.9 Hz



Craig-Chang

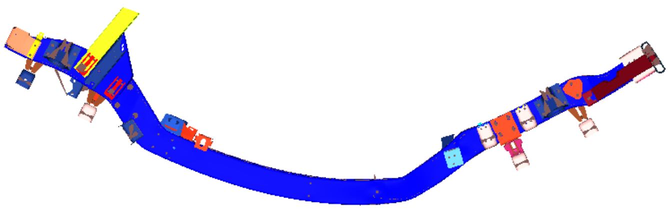
Mode Shape 2
ω_2 = 22.5 Hz



Frame Mode Shapes and Natural Frequencies

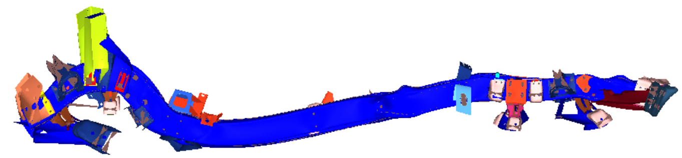
Craig-Bampton

Mode Shape 3
ω_3 = 28.1 Hz



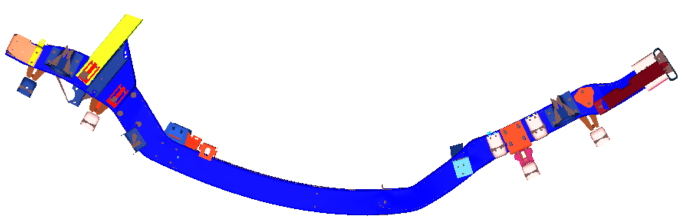
Craig-Bampton

Mode Shape 95
ω_{95} = 382.0 Hz



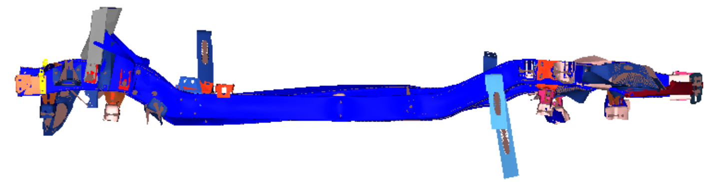
Craig-Chang

Mode Shape 3
ω_3 = 28.0 Hz



Craig-Chang

Mode Shape 95
ω_{95} = 355.4 Hz



Equipment Enclosure CMS Results

Craig-Bampton Method

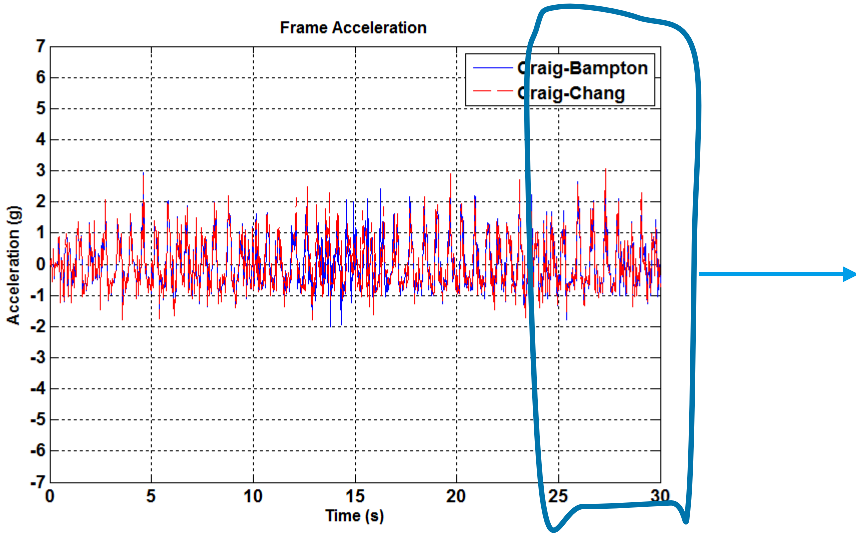
Mode Shape	Natural Frequency (Hz)
1	14.9
2	21.7
3	28.8
4	31.5
5	37.0
6	43.8
7	44.6
8	49.2
9	49.5
10	50.2
.	.
Highest	49,208

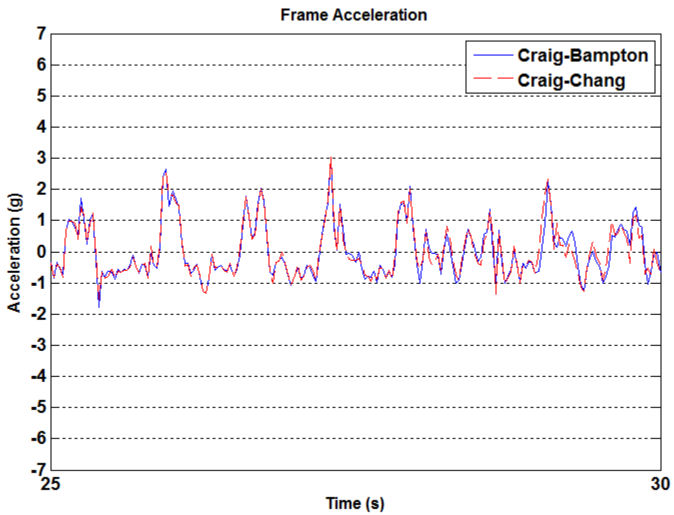
- 96 static modes
- 97 normal modes

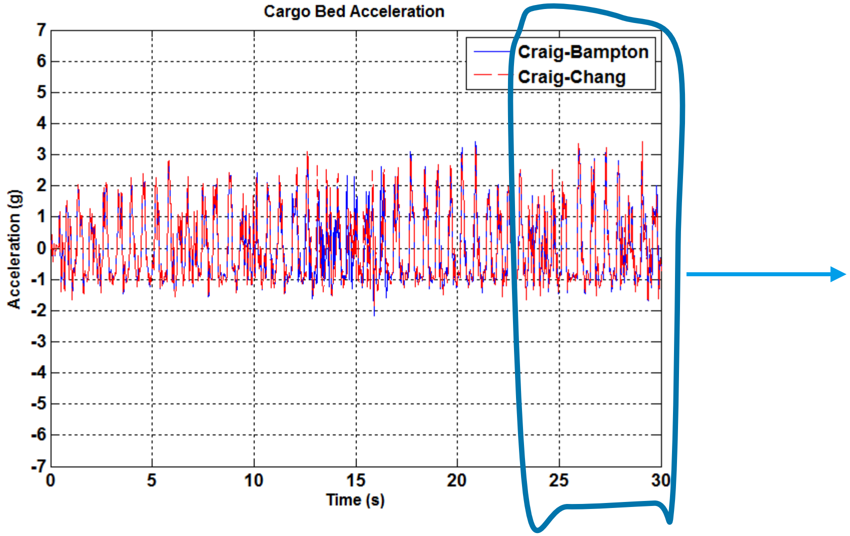
CMS Modes

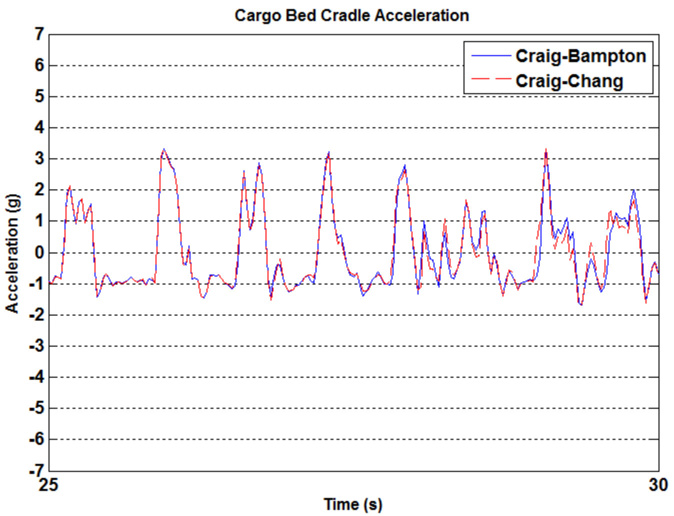
- 179 orthonormalized modes

Influence of CMS Method on the Model Dynamics
Random Road RMS 3.5"









Influence of CMS Method on the Model Dynamics
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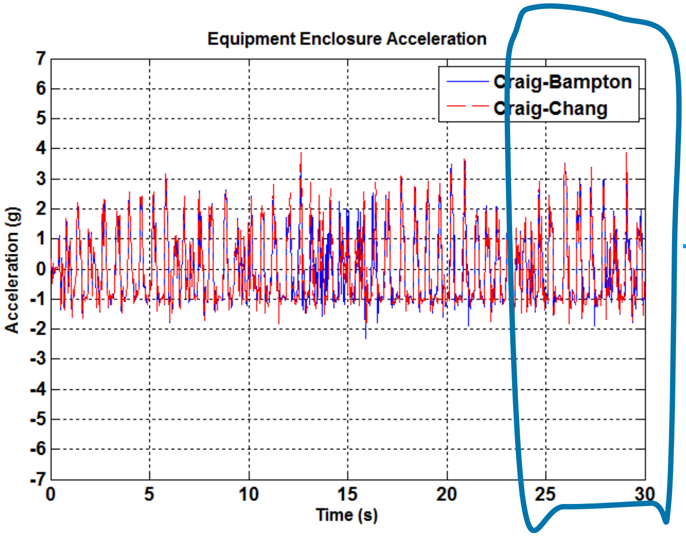

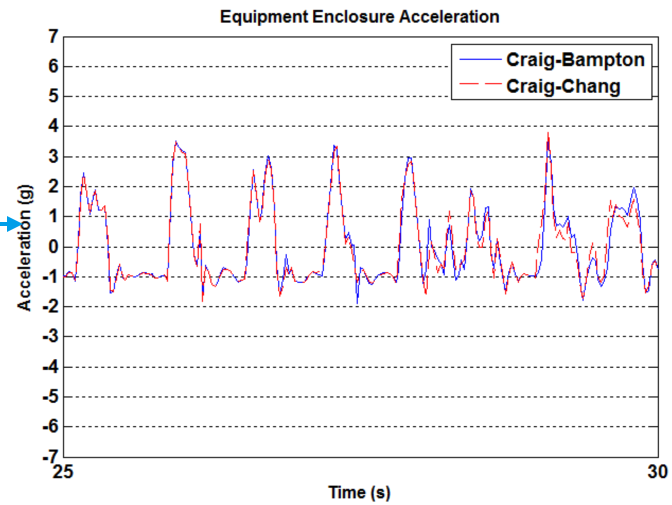

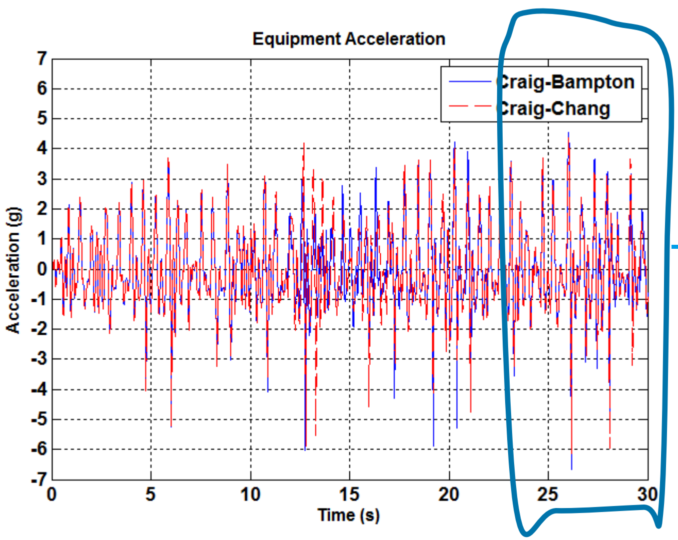

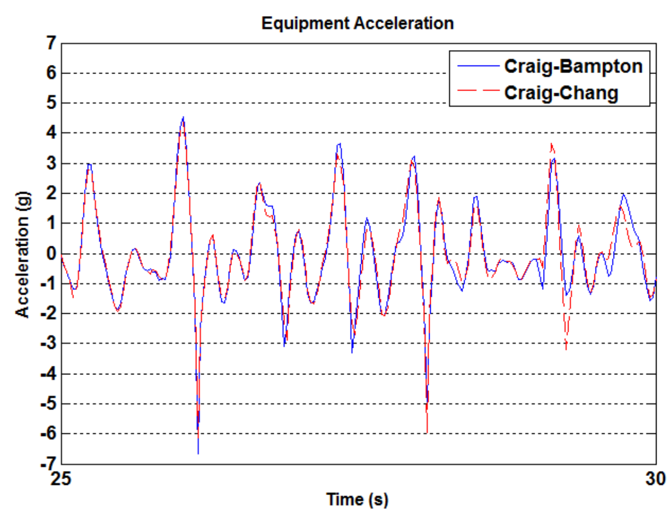

Craig-Bampton

Max	Min
4.5 g	-6.4 g

Craig-Chang

Max	Min
4.4 g	-6.3 g

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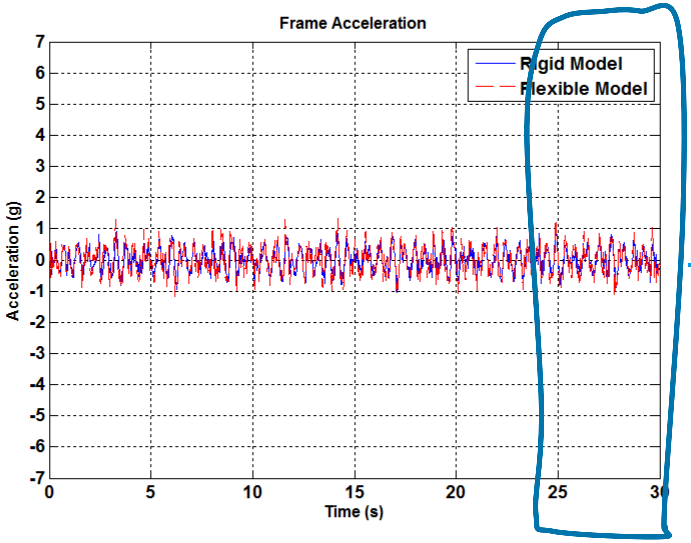
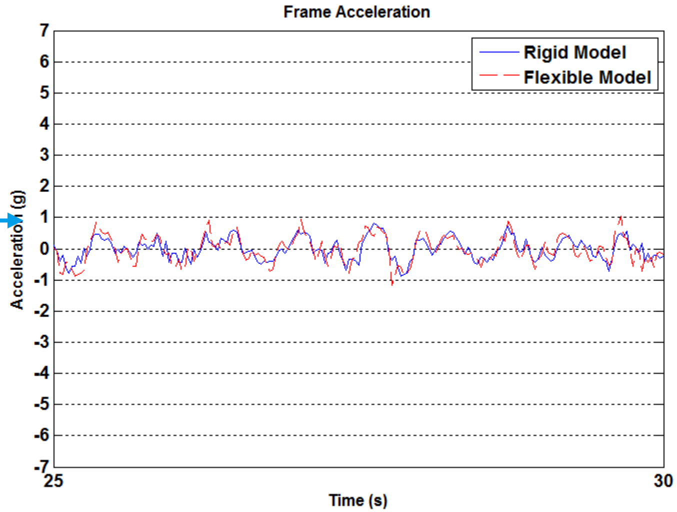
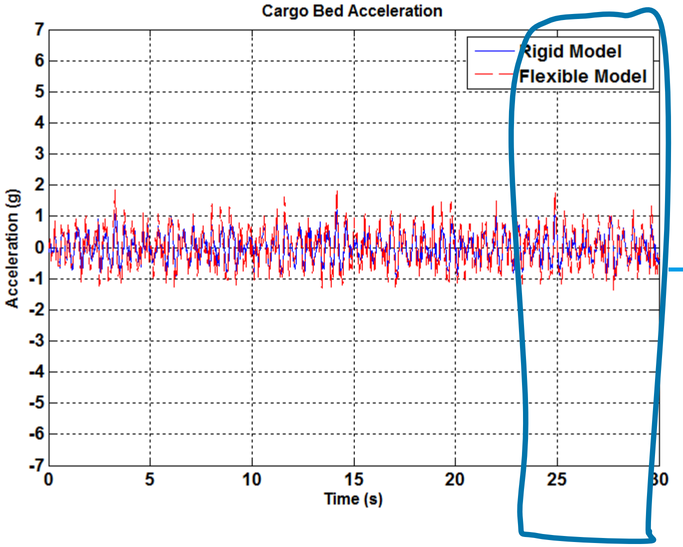
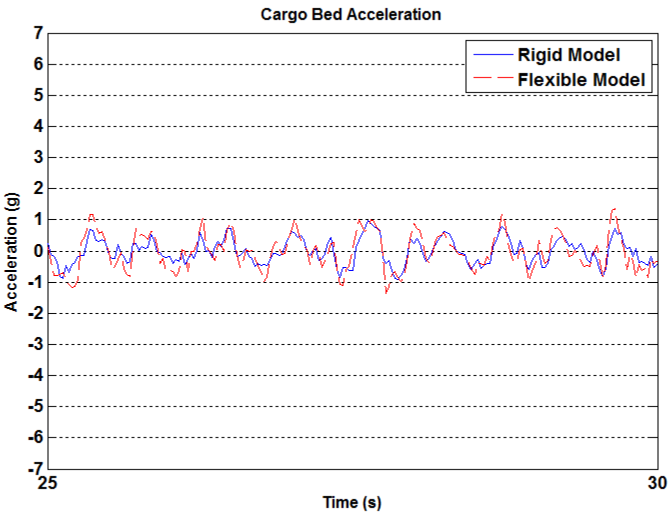
Influence of Flexibility on the Model Dynamics Random Road RMS 1.0"









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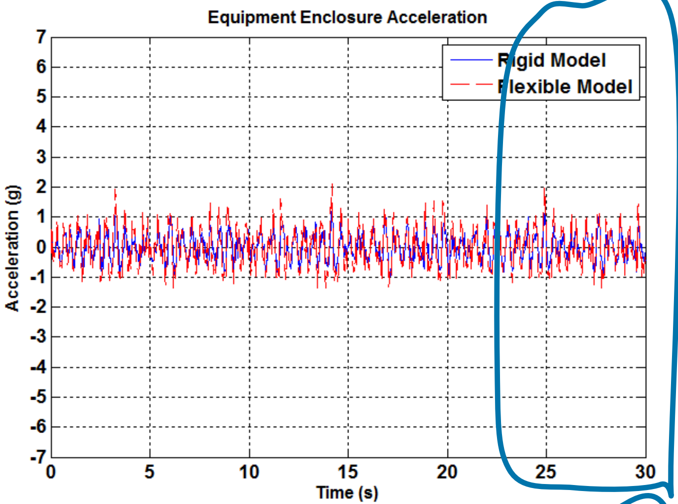
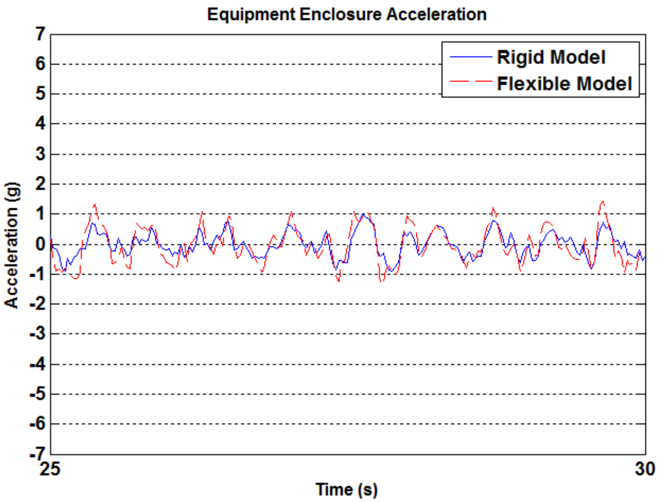
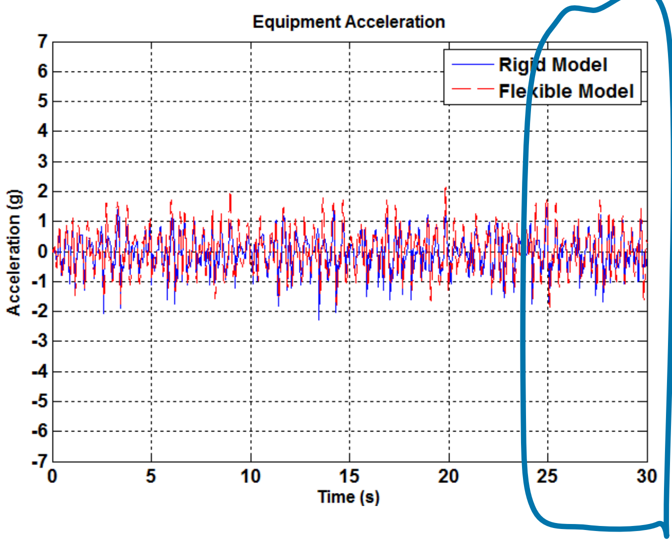
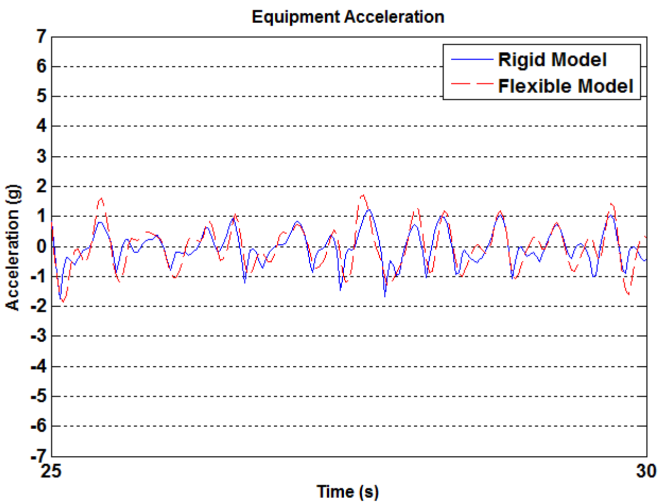
Influence of Flexibility on the Model Dynamics
Random Road RMS 1.0"

- Flexible components were obtained using Craig-Bampton method

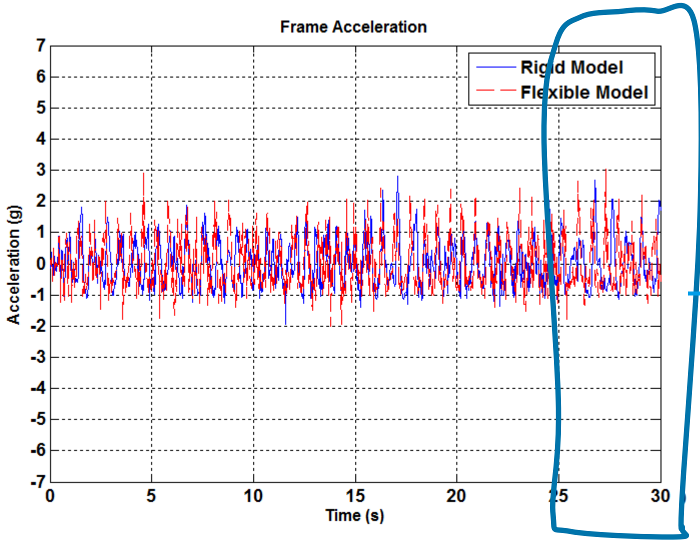


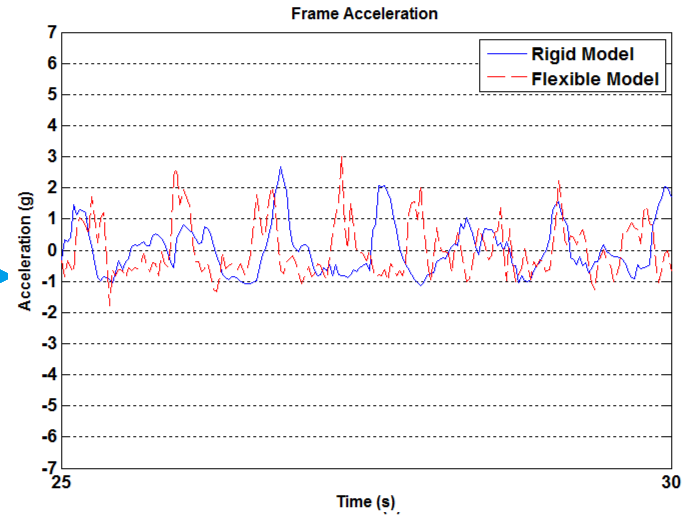






Influence of Flexibility on the Model Dynamics
Random Road RMS 3.5"



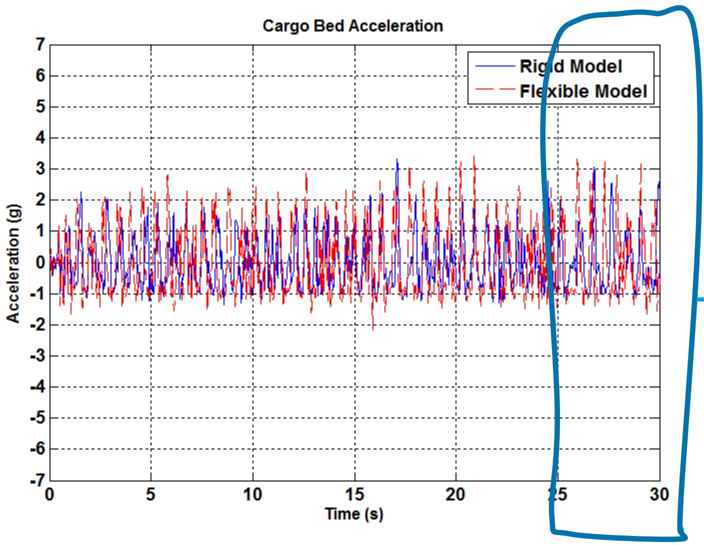


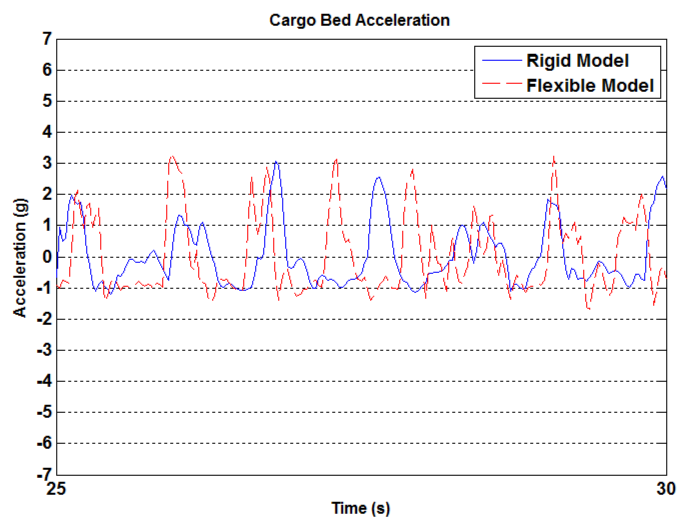
Rigid acceleration

Max	Min
2.8 g	-1.9 g

Flex acceleration

Max	Min
3.0 g	-2.0 g





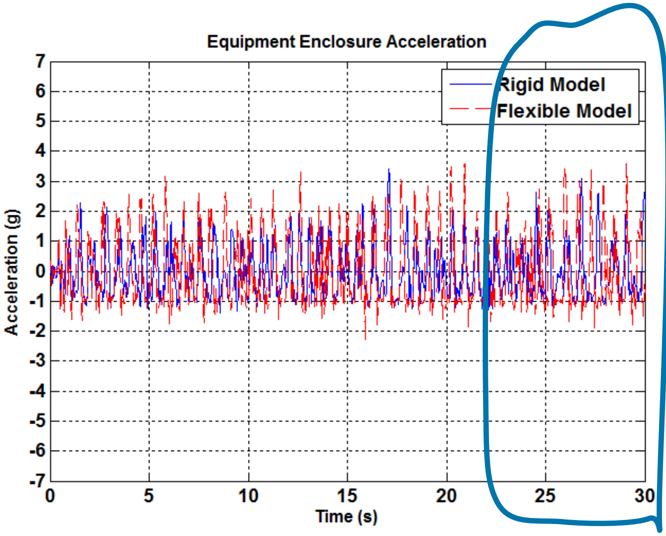
Rigid acceleration

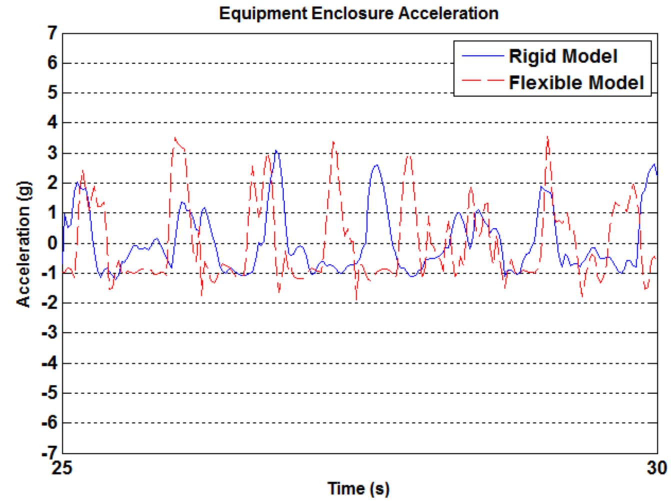
Max	Min
3.3 g	-1.4 g

Flex acceleration

Max	Min
3.4 g	-2.2 g

Influence of Flexibility on the Model Dynamics
Random Road RMS 3.5"



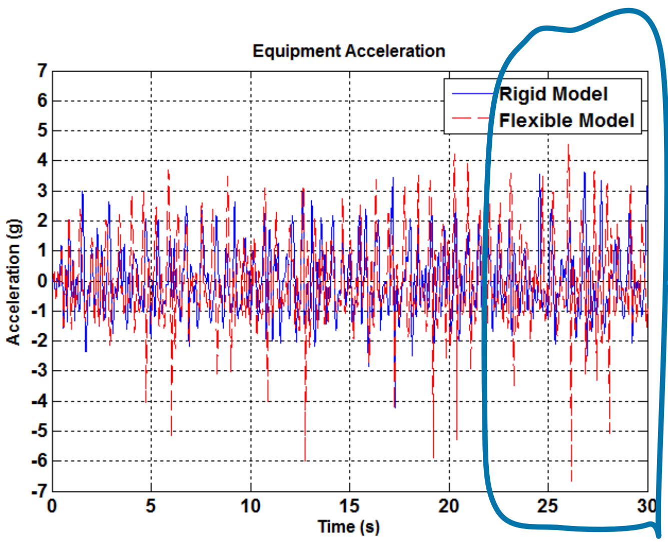


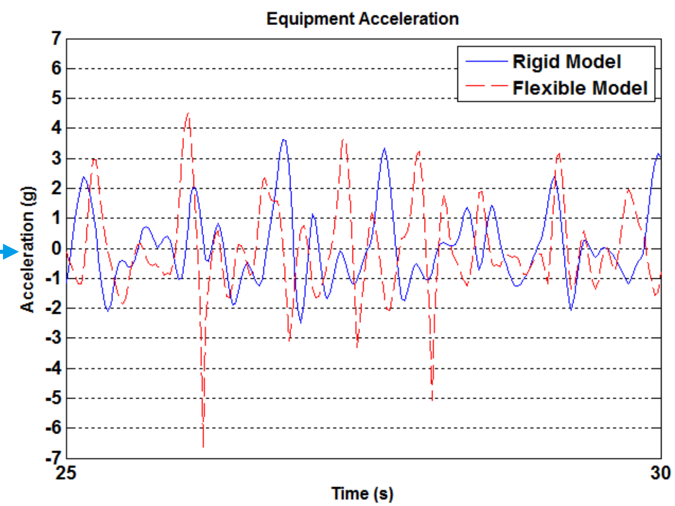
Rigid acceleration

Max	Min
3.4 g	-1.4 g

Flex acceleration

Max	Min
3.6 g	-2.3 g





Rigid acceleration

Max	Min
3.6 g	-4.2 g

Flex acceleration

Max	Min
4.5 g	-6.6 g

Conclusions

- Developed a vehicle model that carries a precision equipment, the latter can be reliably used. In order to function properly, its vibration is minimized; the vibration coming through the suspension is suppressed by isolator mounts.
- Integrated flexible components (frame, equipment enclosure, and equipment) into the vehicle rigid model using CMS.
- Equipment system vibration was not affected by the type of CMS method.
- Equipment acceleration increased by 50 % when the model is flexible, for rough roads (3.5" rms).